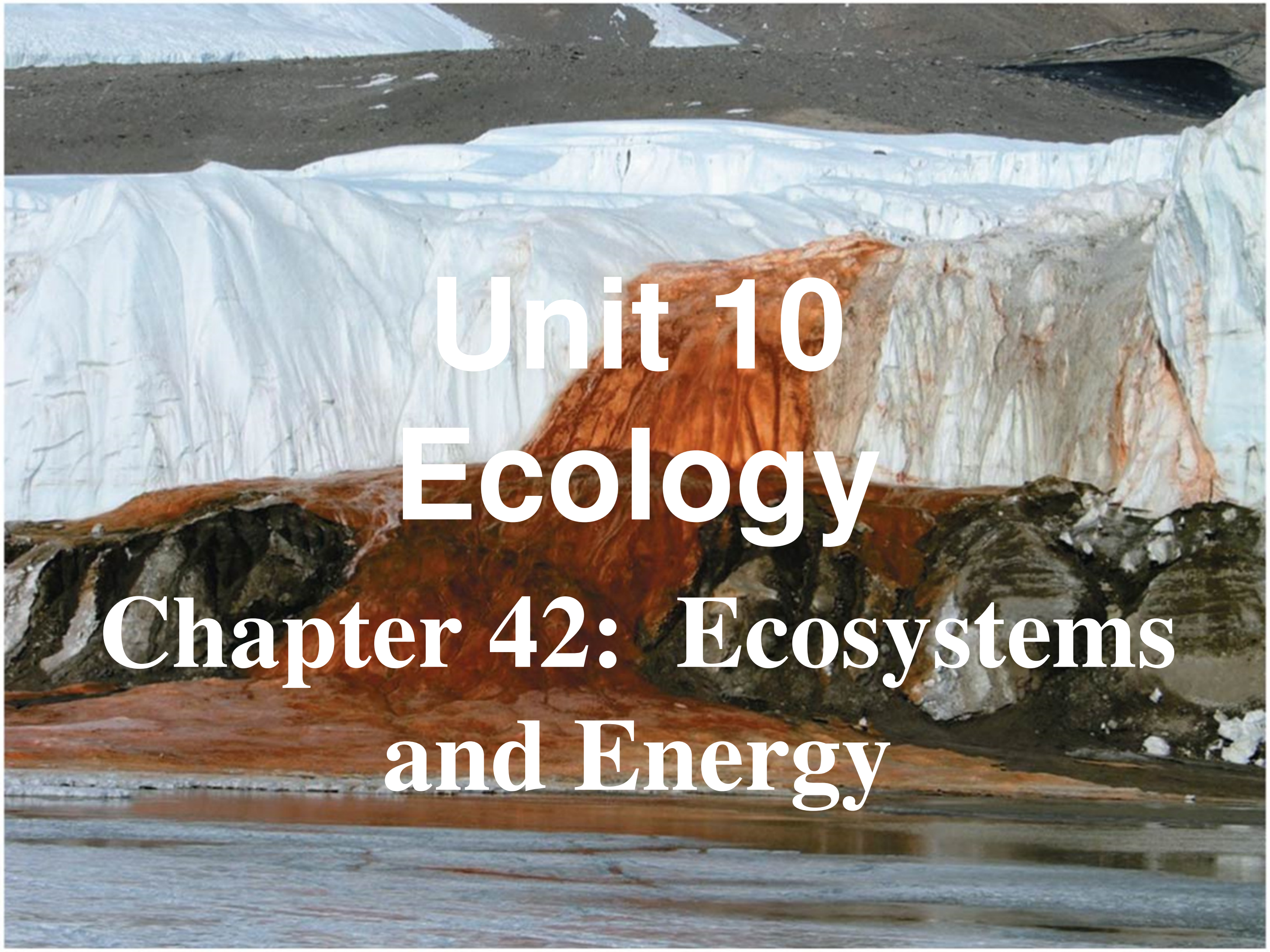


Unit 10
Ecology

Chapter 42: Ecosystems and Energy

Overview: Cool Ecosystem

- An **ecosystem** consists of all the organisms living in a community, as well as the abiotic factors with which they interact
  - Range from a microcosm, such as space under a fallen log or desert spring, to a large area, such as a lake or forest
- Regardless of an ecosystem's size, its dynamics involve two main processes:
  - Energy flow
  - Chemical cycling

- Energy flows through ecosystems
  - Energy enters most ecosystems as sunlight
  - Converted to chemical energy by autotrophs
  - Passed to heterotrophs in food
  - Dissipated as heat
- Matter cycles within ecosystems
  - Chemical elements, like carbon and nitrogen, are cycled among abiotic and biotic components of ecosystems
- Both energy and matter are transformed in ecosystems through photosynthesis and feeding relationships
  - But unlike matter, energy cannot be recycled!

Concept 42.1: Physical laws govern energy flow and chemical cycling in ecosystems

- Ecologists study the transformations of energy and matter within ecosystems
- Organisms are grouped into trophic levels based on their feeding relationships

Conservation of Energy

- Laws of physics and chemistry apply to ecosystems, particularly energy flow
- The first law of thermodynamics states that energy cannot be created or destroyed, only transferred or transformed
  - Energy enters an ecosystem as solar radiation
  - Transformed into chemical energy by photosynthetic organisms
  - Dissipated as heat
    - Total amount of energy does not change!

- The second law of thermodynamics states that every exchange of energy increases the entropy of the universe
  - In an ecosystem, energy conversions are not completely efficient
    - Some energy is always lost as heat
  - Continuous input from the sun is required to maintain energy flow in Earth's ecosystems

Conservation of Mass

- The **law of conservation of mass** states that matter cannot be created or destroyed
- Chemical elements are continually recycled within ecosystems
- Ecosystems are open systems
  - Absorb energy and mass
  - Release heat and waste products

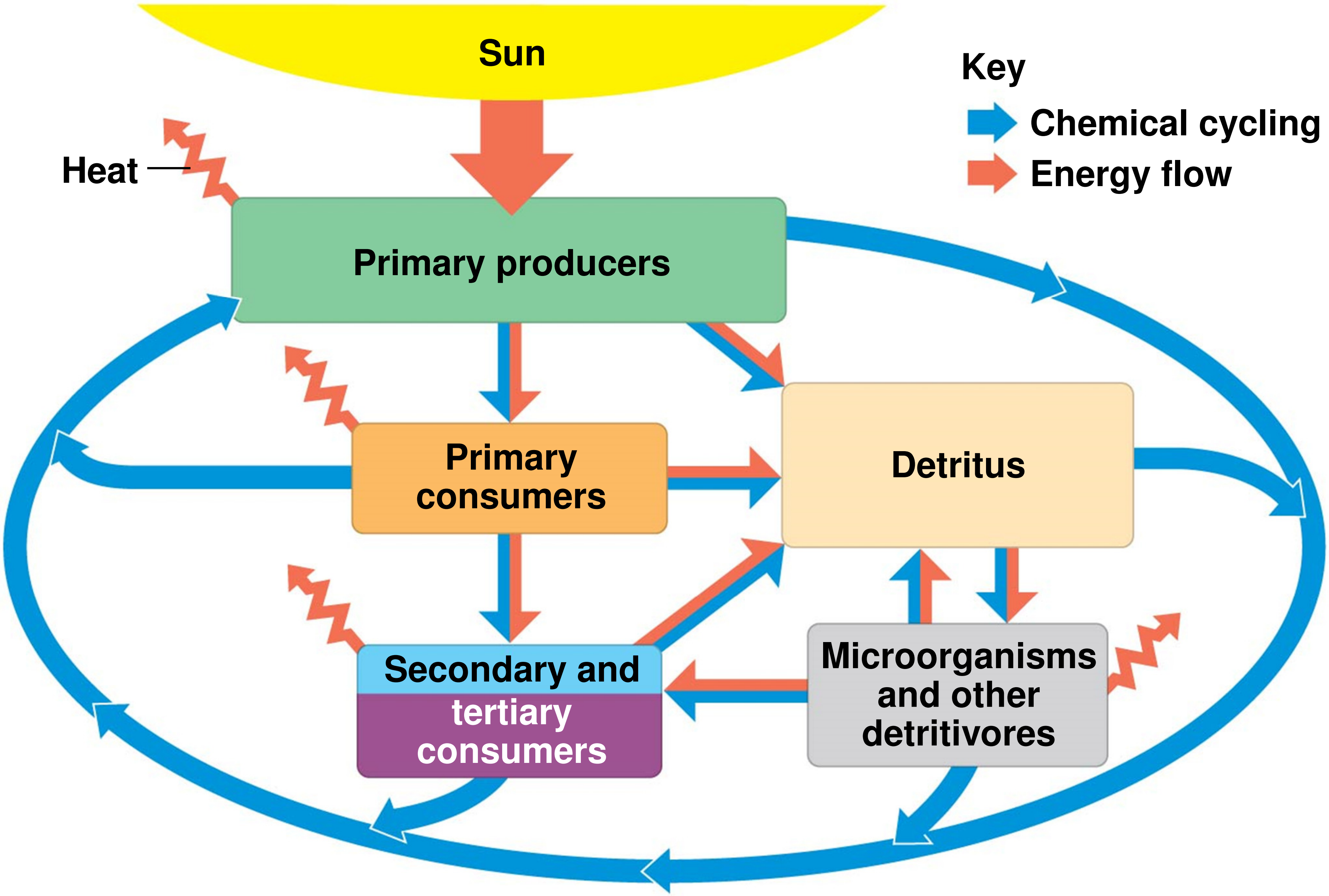
Energy, Mass, and Trophic Levels

- Autotrophs build molecules themselves using photosynthesis or chemosynthesis as an energy source
  - Ultimately support all other feeding levels
- Heterotrophs depend on the biosynthetic output of other organisms
  - Depend directly or indirectly on primary producers for their source of energy

- Energy and nutrients pass
  - From **primary producers** (autotrophs)
  - To **primary consumers** (herbivores)
  - To **secondary consumers** (carnivores)
  - To **tertiary consumers** (carnivores that feed on other carnivores)

- **Detritivores,** or **decomposers**, are consumers that derive their energy from **detritus**
  - Nonliving organic matter
- Prokaryotes and fungi are important detritivores
- Decomposition connects all trophic levels
  - Detritivores are fed upon by secondary and tertiary consumers

Figure 42.4


Sun
Key
Chemical cycling
Energy flow
Heat
Primary producers
Primary consumers
Detritus
Secondary and tertiary consumers
Microorganisms and other detritivores

Concept 42.2: Energy and other limiting factors control primary production in ecosystems

- In most ecosystems, **primary production** is the amount of light energy converted to chemical energy by autotrophs during a given time period
- In a few ecosystems, chemoautotrophs are the primary producers
- The extent of photosynthetic production sets the “spending limit” for an ecosystem’s energy “budget”

The Global Energy Budget

- The amount of solar radiation reaching Earth's surface limits the photosynthetic output of ecosystems
  - Only a small fraction of solar energy actually strikes photosynthetic organisms, and even less is of a usable wavelength

Gross and Net Production

- Total primary production is known as the ecosystem's **gross primary production (GPP)**
  - GPP is measured as the amount of energy from light converted to the chemical energy of organic molecules per unit time
- **Net primary production (NPP)** is GPP minus energy used by primary producers for "autotrophic respiration" (R_a)

$$NPP = GPP - R_a$$

  - NPP is expressed as
    - Energy per unit area per unit time ($J/m^2 \cdot yr$), or
    - Biomass added per unit area per unit time ($g/m^2 \cdot yr$)

- On average, NPP is about ½ of GPP
- *Standing crop* is the total biomass of photosynthetic autotrophs at a given time
- NPP is the amount of *new* biomass added in a given time period
  - Only NPP is available to consumers!
- Tropical rain forests, estuaries, and coral reefs are among the most productive ecosystems per unit area
- Marine ecosystems are relatively unproductive per unit area but contribute much to global net primary production because of their volume

- **Net ecosystem production (NEP)** is a measure of the total biomass accumulation during a given period
  - NEP is gross primary production minus the total respiration of ALL organisms (producers and consumers) in an ecosystem (R_T)

$$NEP = GPP - R_T$$

- NEP is useful because its value determines whether ecosystems are gaining or losing carbon over time
- NEP is estimated by comparing the net flux of CO_2 and O_2 entering or leaving the ecosystem
  - Two molecules connected by photosynthesis
  - The release of O_2 by a system is an indication that it is also storing CO_2

Primary Production in Aquatic Ecosystems

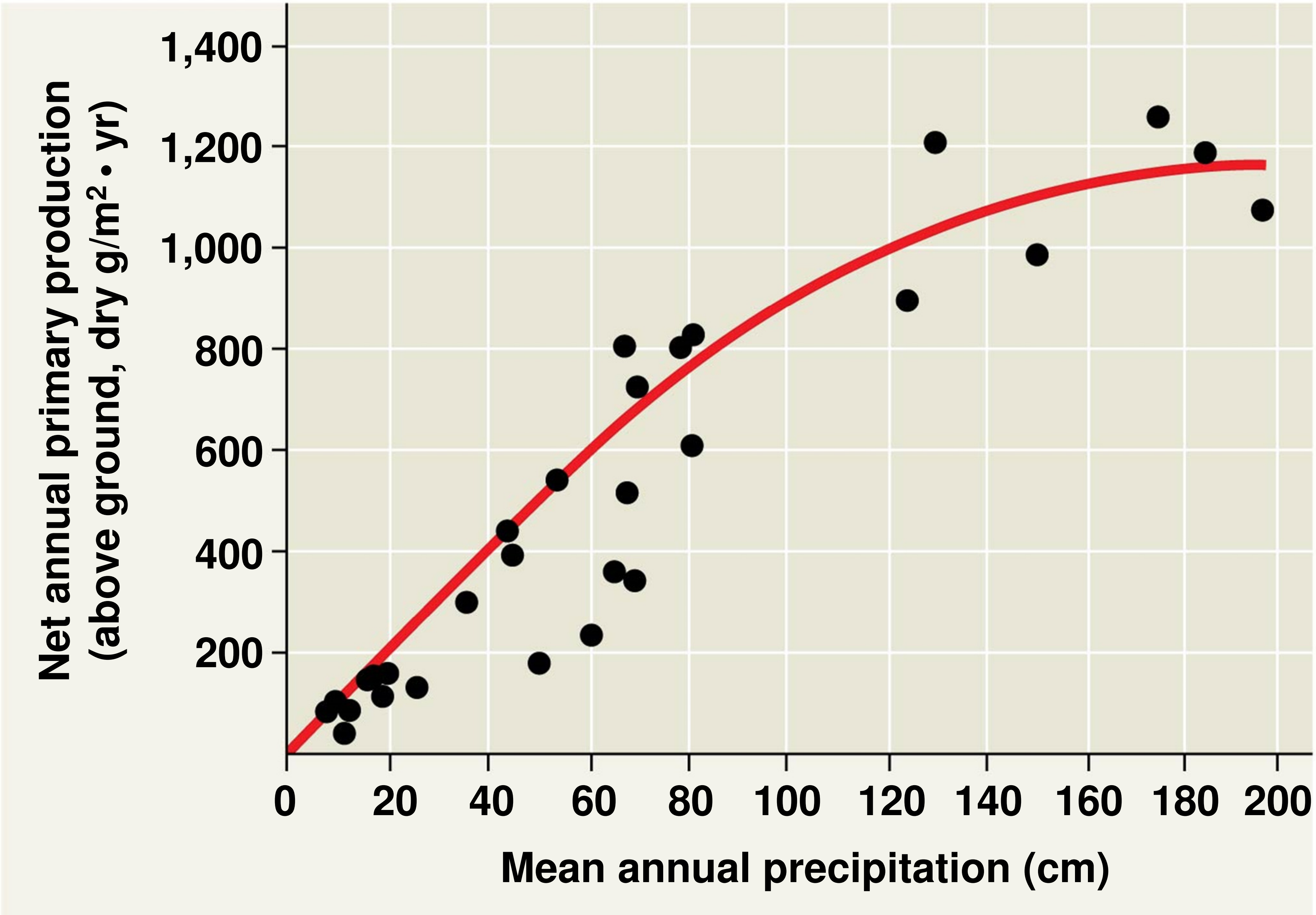
- In marine and freshwater ecosystems, both light and nutrients control primary production
  - Depth of light penetration affects primary production in the photic zone of an ocean or lake
  - More than light, nutrients limit primary production in geographic regions of the ocean and in lakes
    - A **limiting nutrient** is the element that must be added for production to increase in an area
      - Nitrogen and phosphorous are the nutrients that most often limit marine production

- Upwelling of nutrient-rich waters in parts of the oceans contributes to regions of high primary production
- The addition of large amounts of nutrients to lakes has a wide range of ecological impacts, including **eutrophication**
  - In some areas, sewage and fertilizer runoff adds lots of nutrients to lakes
  - Causes cyanobacteria and algae to grow rapidly
  - When the primary producers die, they are broken down by detritivores that use up oxygen
  - Kills fish and other animals

Primary Production in Terrestrial Ecosystems

- In terrestrial ecosystems, temperature and moisture affect primary production on a large scale
  - Primary production increases with moisture
- *Actual evapotranspiration* is the water transpired by plants and evaporated from a landscape
  - Affected by precipitation, temperature, and solar energy
  - Can be used as a predictor of net primary production

Figure 42.8


Net annual primary production
(above ground, dry g/m² • yr)
1,400
1,200
1,000
800
600
400
200
0
20
40
60
80
100
120
140
160
180
200
Mean annual precipitation (cm)

Nutrient Limitations and Adaptations That Reduce Them

- On a more local scale, a soil nutrient is often the limiting factor in primary production
  - In terrestrial ecosystems, nitrogen is the most common limiting nutrient
  - Phosphorus can also be a limiting nutrient, especially in older soils
- Farmers maximize the crop yields by using fertilizers with the right balance of nutrients

- Various adaptations help plants access limiting nutrients from soil
  - Some plants form mutualisms with nitrogen-fixing bacteria
  - Many plants form mutualisms with mycorrhizal fungi
    - These fungi supply plants with phosphorus and other limiting elements
  - Roots have root hairs that increase surface area
  - Many plants release enzymes that increase the availability of limiting nutrients

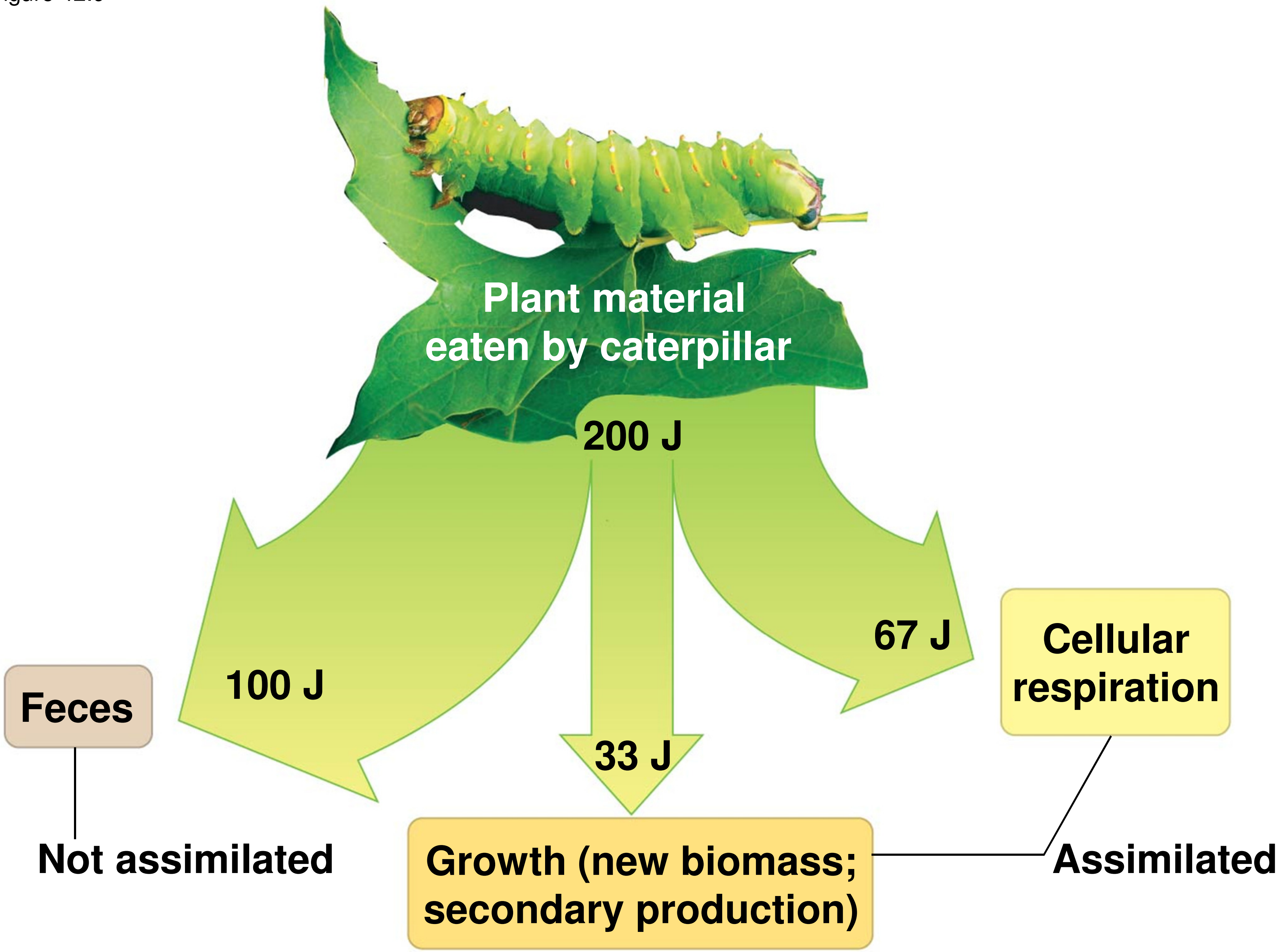
Concept 42.3: Energy transfer between trophic levels is typically only 10% efficient

- **Secondary production** of an ecosystem is the amount of chemical energy in food converted to new biomass during a given period of time

Production Efficiency

- When a caterpillar feeds on a leaf, only about one-sixth of the leaf's energy is used for secondary production, or growth
  - Some energy is stored
  - Some passes through waste
  - Some is lost as heat
- Net secondary production is the energy stored in biomass
  - Only the chemical energy stored by herbivores as biomass is available as food to secondary consumers

Figure 42.9


Plant material eaten by caterpillar
200 J
100 J
Feces
33 J
67 J
Cellular respiration
Growth (new biomass; secondary production)
Not assimilated
Assimilated

- An organism's **production efficiency** is the fraction of energy stored in food that is not used for respiration

$$\text{Production efficiency} = \frac{\text{Net secondary production} \times 100\%}{\text{Assimilation of primary production}}$$

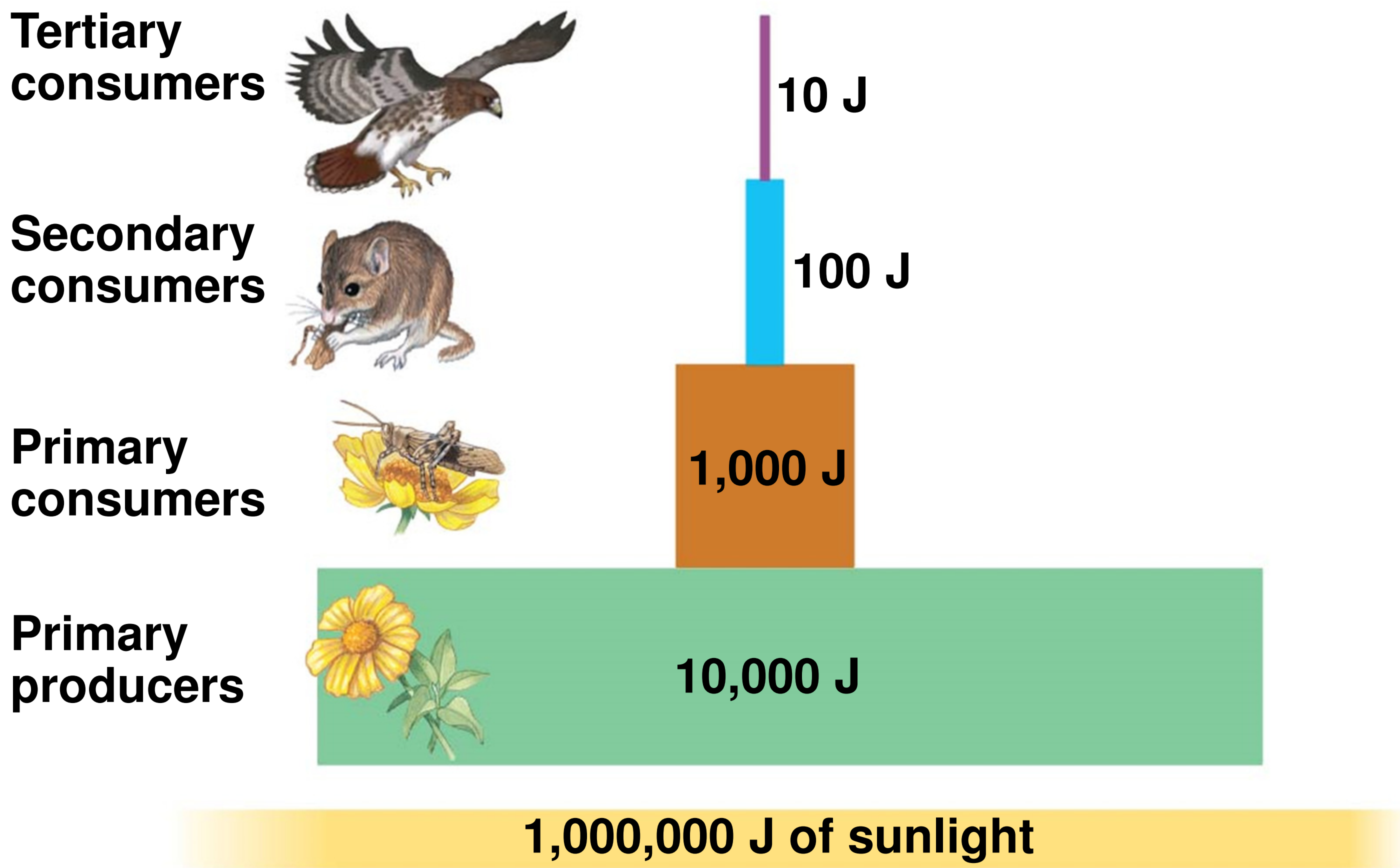
- Birds and mammals have lower efficiencies because of the high cost of endothermy
  - Maintaining constant, high body temp
- Insects and microorganisms are much more efficient

Trophic Efficiency and Ecological Pyramids

- **Trophic efficiency** is the percentage of production transferred from one trophic level to the next
  - Usually about 10%!
- Trophic efficiencies are always less than production efficiencies
  - Take into account energy lost through respiration and contained in feces, as well as the energy stored in unconsumed portions of the food source
- Trophic efficiency is multiplied over the length of a food chain
  - Explains why most food webs include only about 4 or 5 tropic levels

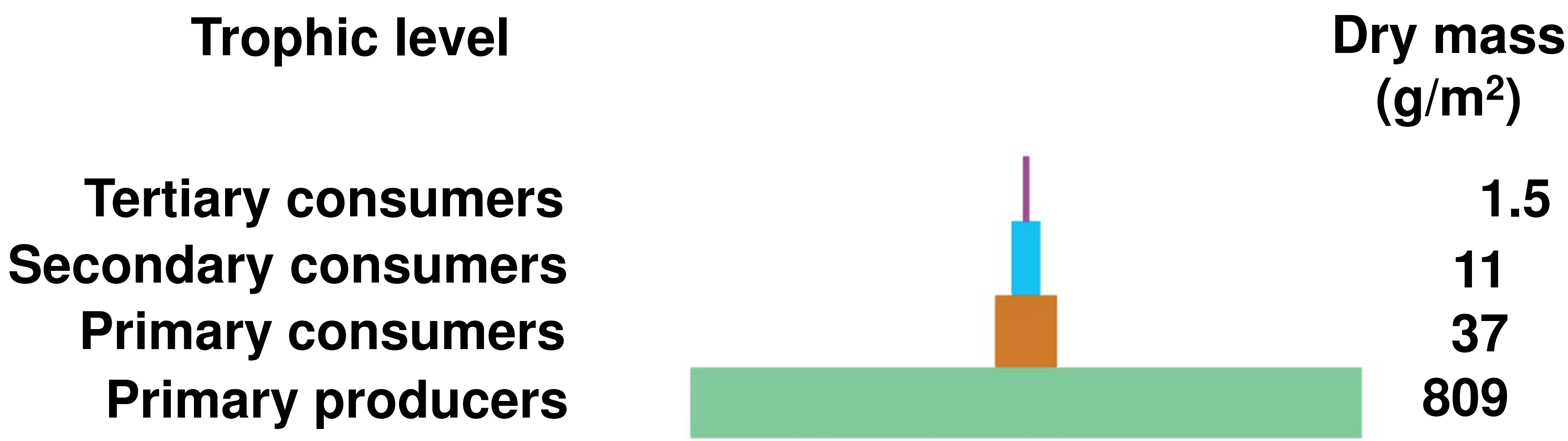
- A *pyramid of net production* represents the loss of energy with each transfer in a food chain
- In a *biomass pyramid*, each tier represents the standing crop (total dry mass of all organisms) in one trophic level
  - Most biomass pyramids show a sharp decrease at successively higher trophic levels
    - Big base, small top
  - Certain aquatic ecosystems have inverted biomass pyramids
    - Producers (phytoplankton) are consumed so quickly that they are outweighed by primary consumers

Figure 42.10



Tertiary consumers
10 J
Secondary consumers
100 J
Primary consumers
1,000 J
Primary producers
10,000 J
1,000,000 J of sunlight

Figure 42.11



(a) Most ecosystems (data from a Florida bog)

(b) Some aquatic ecosystems (data from the English Channel)

Concept 42.4: Biological and geochemical processes cycle nutrients and water in ecosystems

- Life depends on recycling chemical elements
- Decomposers (detritivores) play a key role in the general pattern of chemical cycling

Decomposition and Nutrient Cycling Rates

- Rates at which nutrients cycle in different ecosystems vary greatly, mostly as a result of differing rates of decomposition
- The rate of decomposition is controlled by
  - Temperature
    - Decomposers usually grow faster and decompose material more quickly in warmer ecosystems
  - Moisture
  - Nutrient availability

- Rapid decomposition results in relatively low levels of nutrients in the soil
  - Ex: Material decomposes rapidly in a tropical rain forest and most nutrients are tied up in trees and other living organisms
- Cold and wet ecosystems store large amounts of undecomposed organic matter
  - Decomposition rates are low
- Decomposition is slow in anaerobic muds

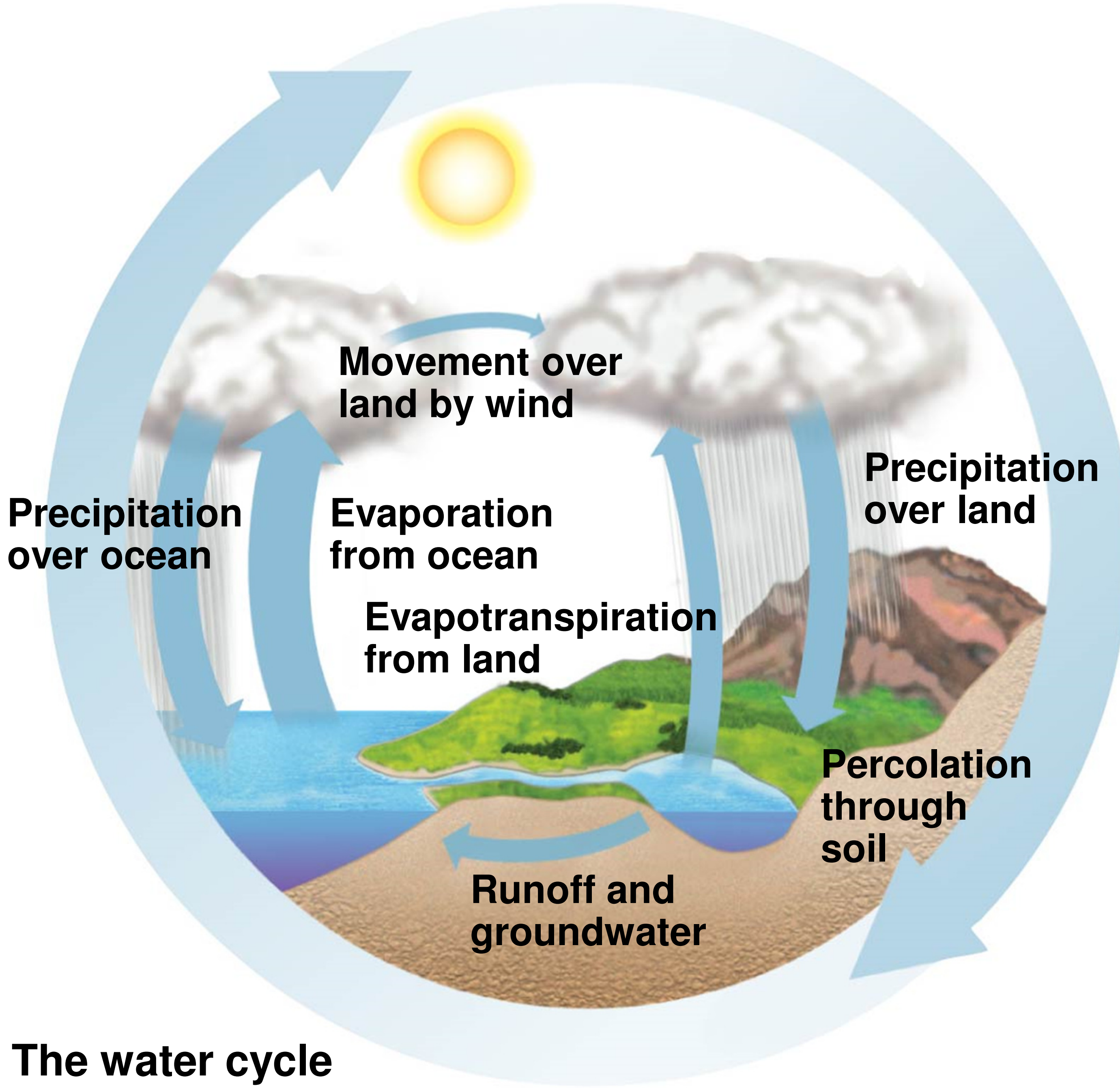
Biogeochemical Cycles

- Nutrient cycles in ecosystems involve biotic and abiotic components and are often called **biogeochemical cycles**
  - Cycle globally and locally
    - Gaseous carbon, oxygen, sulfur, and nitrogen occur in the atmosphere and cycle globally
    - Less mobile elements include phosphorus, potassium, and calcium
      - These elements cycle locally in terrestrial systems but more broadly when dissolved in aquatic systems

The Water Cycle

- Water is essential to all organisms
- Water moves by the processes of
  - Evaporation and transpiration
  - Condensation
  - Precipitation
  - Movement through surface and groundwater

Figure 42.13a

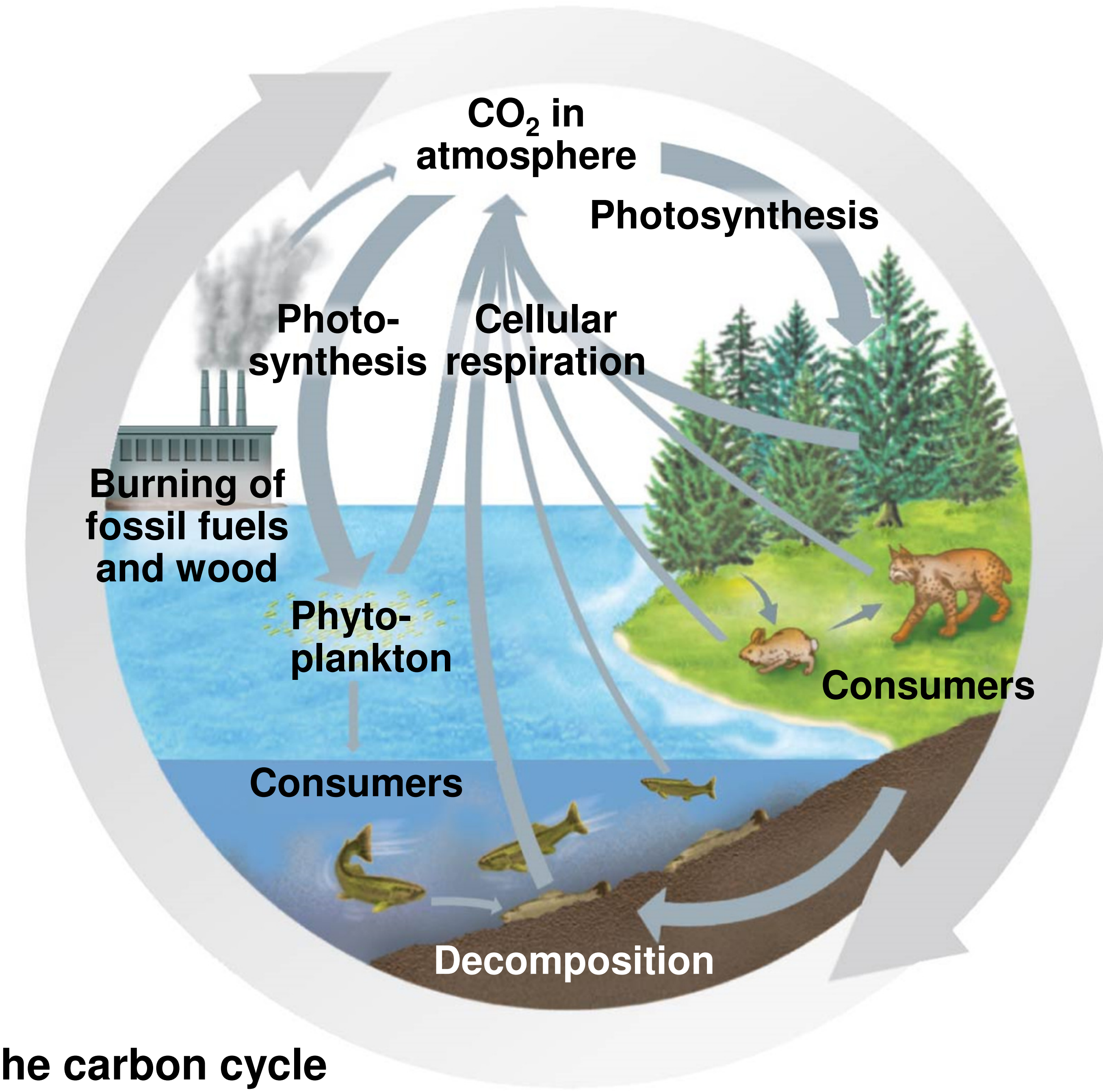


The water cycle

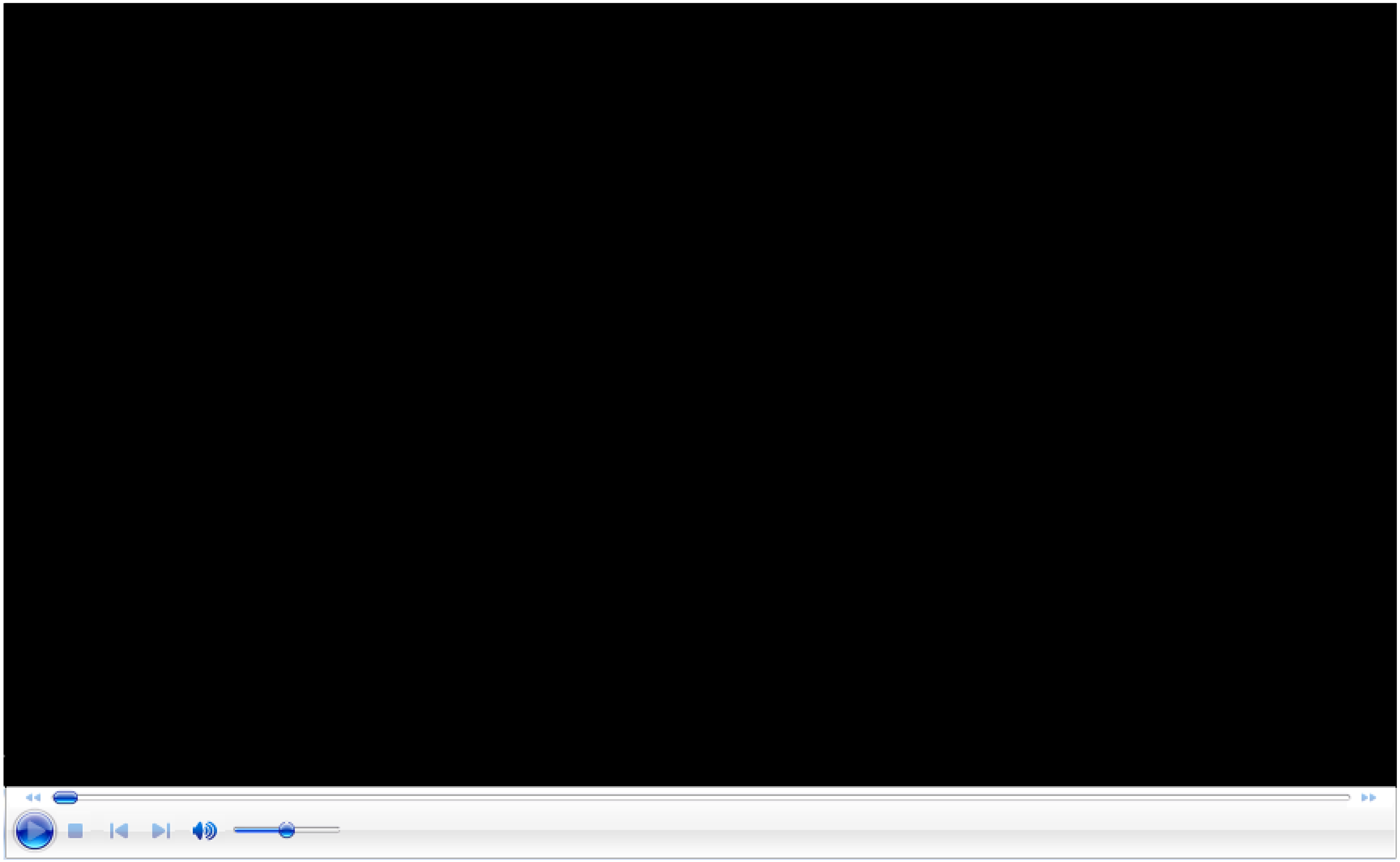
The Carbon Cycle

- Carbon-based organic molecules are essential to all organisms
- Photosynthetic organisms convert CO_2 to organic molecules that are used by heterotrophs
- Carbon reservoirs include fossil fuels, soils and sediments, solutes in oceans, plant and animal biomass, the atmosphere, and sedimentary rocks
- CO_2 is taken up by the process of photosynthesis
- CO_2 is released into the atmosphere through cellular respiration

Figure 42.13b



The carbon cycle

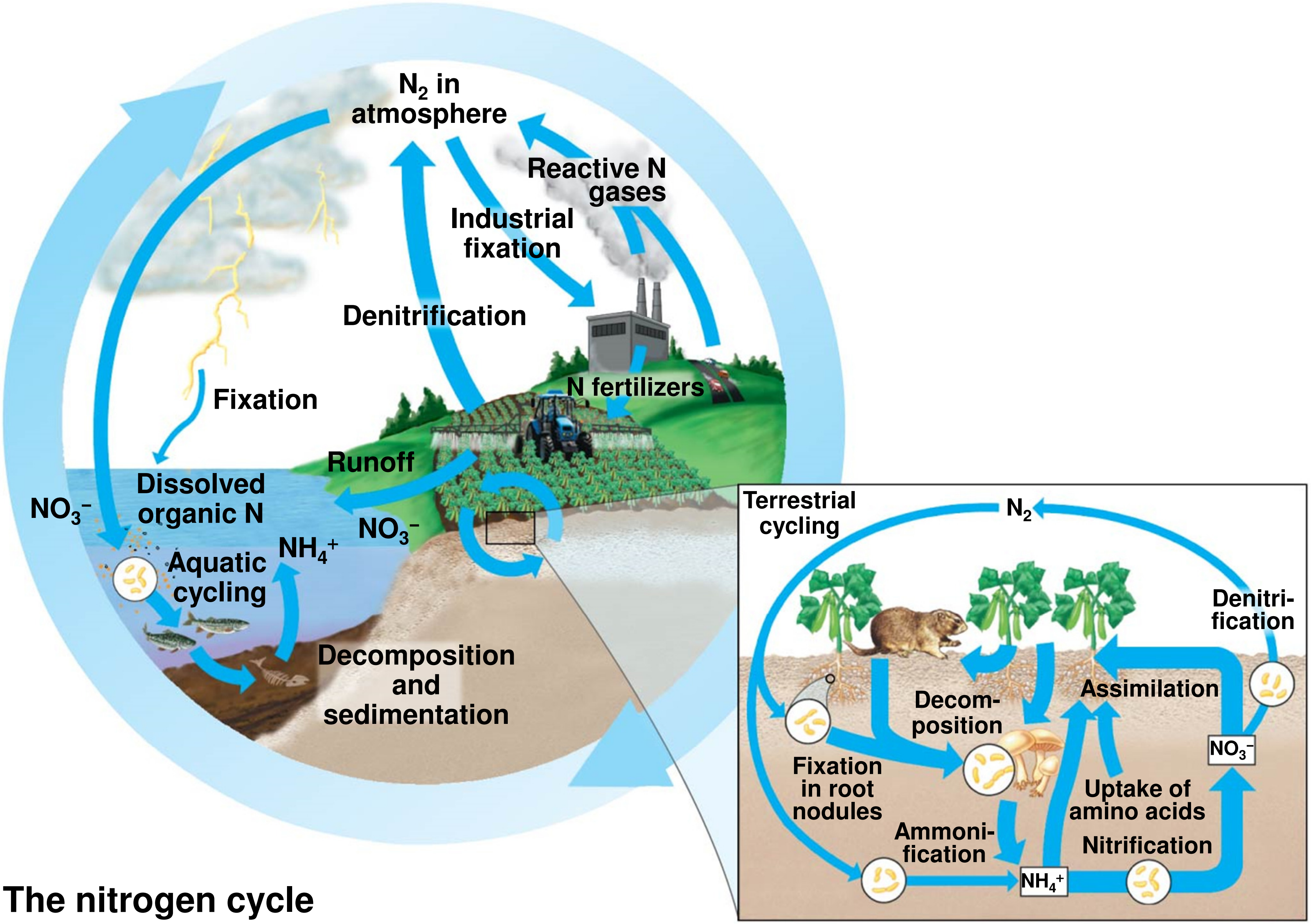


Animation: Carbon Cycle

The Nitrogen Cycle

- Nitrogen is a component of amino acids, proteins, and nucleic acids
- The main reservoir of nitrogen is the atmosphere (N_2)
- Organic nitrogen is decomposed to NH_4^+ by ammonification, and NH_4^+ is decomposed to NO_3^- by nitrification
  - Nitrogen fixation by bacteria
- Denitrification converts NO_3^- back to N_2

Figure 42.13c

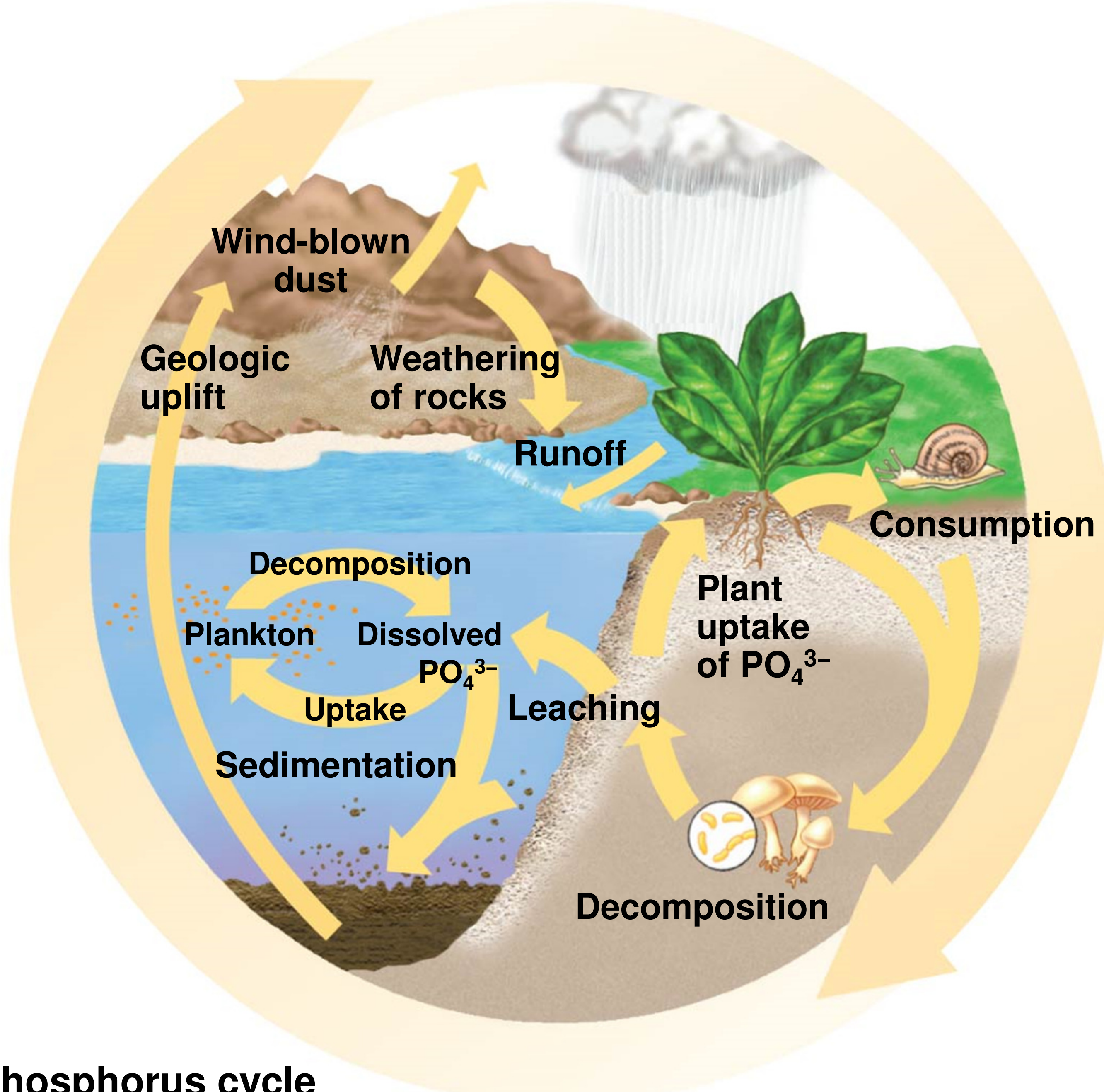


The nitrogen cycle

The Phosphorus Cycle

- Phosphorus is a major constituent of nucleic acids, phospholipids, and ATP
- Phosphate (PO_4^{3-}) is the most important inorganic form of phosphorus
- The largest reservoirs are sedimentary rocks of marine origin, the soil, oceans, and organisms
- Phosphate binds with soil particles, and movement is often localized

Figure 42.13d



The phosphorus cycle

Concept 42.5: Restoration ecologists help return degraded ecosystems to a more natural state

- Given enough time, biological communities can recover from many types of disturbances
- Two key strategies are
  - Bioremediation
  - Augmentation of ecosystem processes

(a) In 1991, before restoration

(b)In 2000, near the completion of restoration

Bioremediation

- **Bioremediation** is the use of organisms to detoxify ecosystems
  - The organisms most often used are prokaryotes, fungi, or plants
  - These organisms can take up, and sometimes metabolize, toxic molecules

Biological Augmentation

- **Biological augmentation** uses organisms to add essential materials to a degraded ecosystem
  - Nitrogen-fixing plants can increase the available nitrogen in soil
  - Adding mycorrhizal fungi can help plants to access nutrients from soil